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OF US COASTLINES

WIS REPORT 28

VERIFICATION OF THE GULF OF MEXICO HINDCAST WAVE INFORMATION

by

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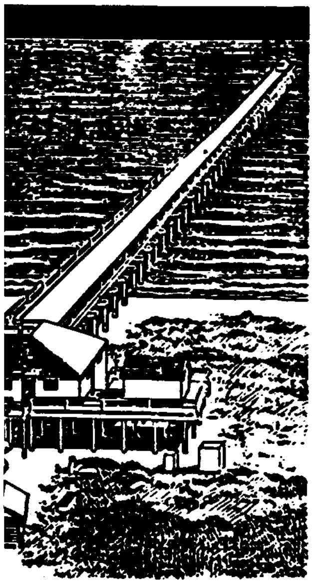

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13. ABSTRACT *(Maximum 200 words)*

The Wave Information Study (WIS) for the Gulf of Mexico (WIS Report 18) provides a wave climate for the US shorelines of the Gulf of Mexico based on simulation of 20 years of weather data from the period 1956-1975. During these years, few wave data exist with which to evaluate the adequacy of the total hindcast procedure, which includes derivation of pressure charts, translation of these into wind estimates, and then calculation of wave conditions. In 1991, CERC conducted a 1-year hindcast of the Gulf of Mexico for the year 1988 and evaluated the model results against extensive wind and wave measurements now available in order to provide guidance on the quality of the previous hindcast work. This report provides a summary of that hindcast and guidance on the use of the earlier WIS study.

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Preface

In late 1976 a study to produce a wave climate for US coastal waters was initiated at the US Army Engineer Waterways Experiment Station (WES). The Wave Information Study (WIS) was authorized by Headquarters, US Army Corps of Engineers (HQUSACE) as part of the Coastal Field Data Collection Program, which is managed by the WES Coastal Engineering Research Center (CERC). Messrs. John H. Lockhart, Jr., John G. Housley, James E. Crews, and Robert H. Campbell, HQUSACE, are Technical Monitors for the Coastal Field Data Collection Program; Ms. Carolyn M. Holmes is Program Manager; and Dr. Jon M. Hubertz is WIS Project Manager.

This report, the 28th in a series, provides information to verify the 20 years of hindcast wave information for the Gulf of Mexico. The information is derived from an evaluation of the winds and wave model (SHALWV) used in the 20-year hindcast. The report was written by Dr. Jon M. Hubertz. Application of the model and preparation of all of the comparison figures and statistical calculations were done by Ms. Rebecca M. Brooks.

The study was conducted under the direct supervision of Dr. Martin C. Miller, Chief, Coastal Oceanography Branch, CERC, and Mr. H. Lee Butler, Chief, Research Division, CERC; and under the general supervision of Dr. James R. Houston and Mr. Charles C. Calhoun, Jr., Director and Assistant Director, CERC, respectively. Word processing of this report was done by Ms. Jane Stauble, Coastal Oceanography Branch, CERC. Editing was done by Ms. Janean Shirley, Information Technology Laboratory, WES.

At the time of publication of this report, Director of WES was Dr. Robert W. Whalin. Commander and Deputy Director was COL Leonard G. Hassell, EN.

Contents

VERIFICATION OF THE GULF OF MEXICO HINDCAST WAVE INFORMATION

Introduction

1. The Wave Information Study (WIS) has hindcast wave conditions, excluding hurricanes, in the Gulf of Mexico for the period 1956-1975 (Hubertz and Brooks 1989). These results have not been verified against measurements since there are no long-term time series measurements of wave conditions available in this time period to compare to the hindcast results. The study results have been verified in a climatological sense by comparing the occurrences of wave heights and peak periods in various height and period categories to measurements collected after the hindcast period. This was done by comparing the percent distribution of hindcast wave heights and peak periods from the 20-year period 1956-1975 to measurements from buoys and coastal gages over various time periods beginning in 1976 and ending in 1988. The assumption is made that wave heights and peak periods will be distributed generally in the same manner regardless of time period. Monthly means and maximums of wave height were also compared. It is assumed that means will generally be the same regardless of year.

2. These comparisons, at similar locations, indicated that the distribution of hindcast wave heights and peak periods compared favorably to measurements available during other time periods. The hindcast underestimated the percent of waves less than about 1.25 m by about 25 percent, and monthly means of wave height showed a slight (typically 0.3 m) bias, with the hindcast results being higher than measured at three deep-water buoy sites. Heights in other categories and peak periods generally agreed to within 10 percent. These comparisons did not warrant any cautions in the use of the hindcast results, but also did not allow any statement of hindcast accuracy.

3. The purpose of the study reported herein was to further verify the wave model used for the 1956-75 hindcast and provide some estimate of hindcast accuracy. This report expands on summary conclusions reported in Coastal Engineering Technical Note I-48 (1991). The model used in the original hindcast for 1956-75 was applied for the period from January through December 1988, when measured data were available from a number of buoys in the Gulf of Mexico. The hindcast and measured time series of wave heights and peak

periods during 1988 were then compared. This provides a statistical measure of model performance. Wave model performance is dependent on the accuracy of the winds input into the model. Thus, conclusions on the accuracy of the 20 years of hindcast wave information have to be qualified by the accuracy of the input winds.

4. In the original 20-year hindcast for the Gulf of Mexico, much time and effort were devoted to obtaining accurate wind fields. In order to apply the conclusions of the present study to the results of the 20-year hindcast, one has to assume that the wind fields used previously are equivalent in quality to those used in this 1-year hindcast. This is addressed in more detail in the section on wind data input to the models.

Wave Data Used for Verification

5. The National Oceanic and Atmospheric Administration (NOAA) operated six buoys in the Gulf of Mexico in 1988. In addition to these, the University of Florida made wave measurements near Clearwater, FL as part of Florida's Coastal Data Network (CDN). The locations of all of these measurements are summarized in Table 1 and shown in Figure 1, along with the locations where WIS results are available. None of the measurements supplied directional wave information.

6. The wave height used in this report is an energy-based value calculated by multiplying the square root of the total energy in a spectrum by 4. Wave period was determined by taking the reciprocal of the wave frequency associated with the largest energy value in the spectrum. These values are referred to as significant wave height H_s and peak wave period T_p, respectively. The NOAA buoys also measured wind speed and wind direction. The wave model verification consists of comparing measured and modeled values of H_s and T_p in a time sequence by months during 1988 and calculating certain statistics to characterize the agreement.

Wind Data Used as Input to the Wave Model

7. The wind data used in the original hindcast for 1956-75 were calculated from US Weather Bureau maps of surface atmospheric pressure over

the Gulf of Mexico using the procedures described in WIS Report 4 (Resio, Vincent, and Corson 1982). Isobars (the locus of points of equal pressure) were digitized on a 30-nm grid over the Gulf of Mexico.

8. The wind data used as input to the wave model for the 1988 hindcast were obtained from the US Navy's Fleet Numerical Oceanographic Center (FNOC). This organization routinely estimates surface (19.5-m elevation) wind speed and direction on a global basis at a resolution of 2.5 deg in space and 6 hr in time. Estimates are made using US Weather Bureau data, atmospheric numerical models, and observed data from ships, buoys, and satellites.

9. Winds produced for recent years by the US Navy for the Gulf of Mexico region may not necessarily be better than those produced by WIS for the 1956-75 period. Present atmospheric models and techniques are improved over past ones and there are more observed data for present years, but the resolution in space and attention to details of weather in the Gulf of Mexico is less than that used to produce the WIS winds for 1956-75.

10. Two comparisons are presented to verify the wind data used in the 20-year hindcast. The first is a time series comparison of wind speeds and directions using data from an NOAA buoy in 1975. The second is a comparison of the distribution of wind speeds and directions using climatic summaries from NOAA buoys at three different locations in the Gulf of Mexico for the period 1976-88.

11. In Appendix A, wind speeds and directions from NOAA buoy EB10, one of the first placed in the Gulf of Mexico, are compared to values calculated by the WIS hindcast for the period 1 October 1975 to 31 December 1975. The WIS speeds and directions generally follow those measured by instruments on the buoy. The bias (WIS-buoy) and root mean square (RMS) difference for the months of October, November, and December are respectively 1.8, 1.2, and 1.5 knots* for the bias and 4.0, 4.2, and 5.6 for the RMS difference. The average RMS is 4.6 knots, and there is a slight bias (an average of 1.5 knots) for WIS to be higher. This can be seen in the wind speed plots, especially for lower wind speeds (pp A3-A5).

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* To convert knots to meters per second, multiply times a factor of 0.5144444.

12. Table 2 is a summary, by month, of the biases and RMS differences of FNOC wind speeds with respect to buoy measurements for 1988. Buoy locations are shown in Figure 1. No wind measurements are available at the Clearwater, FL (CDN) gage site. The biases are calculated by taking the monthly average FNOC wind speed at the buoy location minus the monthly averaged wind speed from the buoy measurements. The FNOC values are available every 6 hr and have been interpolated linearly in time to 3-hr intervals. Buoy measurements are generally available every hour. Only values corresponding to the times from the calculated time series are used to calculate the statistics. Both sets of wind speeds are adjusted to an elevation of 10 m using Equation 3.26 on page 3.26 of the Shore Protection Manual (1984).

13. There is a slight tendency for the FNOC values to be lower than the measured values. Yearly averages of the biases range from -1.3 to -3.2 knots, with most being about -2.5 knots. Yearly averages of the RMS difference values range from 2.9 to 3.7 knots, with most being between 3.0 and 3.5 knots. These results indicate that WIS winds calculated for the period October through December 1975 and FNOC winds calculated for 1988 have similarly low biases and RMS differences compared to measurements.

14. A climatic summary of the distribution of wind speed and direction by categories is available from NOAA buoy measurements over a 13-year period (1976-1988) in the Gulf of Mexico. These results are compared to similar distributions using the WIS results from 1956-1975 (pp. A6-A8). Assuming the wind climate is the same for 1956-1975 as for 1976-1988, a good agreement of the distributions would further verify the WIS winds in a climatological sense.

15. In general, WIS underestimates the percent occurrence of speeds less than 10 knots and overestimates speeds from 11 to 21 knots. The largest disagreement is in the 11- to 16-knot category, where WIS overestimates the number of occurrences by about 20 percent. Other differences are generally less than 10 percent. Similar distributions for direction are also shown in Appendix A (pp. A6-A8). The labeling of direction categories has been divided by 10, so 02-04 represents directions between 20 and 40 deg. The general pattern of direction from which the wind is blowing, as measured by the buoys, is usually matched by the WIS estimates within 5 percent.

16. Values of bias and RMS difference between WIS winds and measurements and FNOC winds and measurements are approximately the same. The distribution of WIS wind speeds and directions in speed and direction categories are similar to the distribution of speeds and directions of winds measured at three locations in the central Gulf of Mexico. Distributions of FNOC speeds and directions are similar to those of measurements, but the measurements are used in calculating the FNOC winds, so agreement is expected. The WIS winds used in the 1956-75 hindcast are thus judged to be of equivalent quality to FNOC winds in 1988, so that using FNOC winds from 1988 in the wave model should be equivalent to using WIS winds from a year during 1956-75.

Wave Model

17. The wave model used to produce the Gulf of Mexico hindcast information for 1956-1975 was SHALWV. It was originally developed under contract by Dr. D. T. Resio of Offshore and Coastal Technology, Inc. (OCTI) and was delivered to the Coastal Engineering Research Center in 1984 for arbitrary depth spectral wave calculations over geographic areas limited in size, so that the curvature of the earth can be neglected. A discussion of the wave model theory and comparisons of model results to measured data are given by Resio in reports published in 1987 and 1988, respectively. A user's guide for application of the model is given by Hughes and Jensen (1986). This model was also used to produce the 20-year (1956-1975) hindcast of wave information along the southern California coast (Jensen et al. 1992).

18. The numerical model SHALWV simulates deep-or shallow-water wave growth, propagation, and decay in a directional spectrum. It is a time-dependent model driven by the input of wind speed and direction at each grid point as a function of time. Results available as output vary from summary information such as height, period, and direction at a point to directional wave spectra over the computational grid. The model is available for use through the Coastal Modeling System (CMS) and is documented in Chapter 7 of the CMS Manual (Cialone 1991).

Verification

19. The verification of the WIS hindcast results for the Gulf of Mexico consists of comparing wave height and peak period as calculated by the wave model using FNOC winds for 1988 to similar height and period values measured at seven different locations during 1988 (Table 1). These comparisons are presented as selected plots of monthly time histories and associated values of bias and RMS differences. Plots were prepared for all months at all measurement sites and were used to evaluate the model results. Only selected plots, typical of the comparisons, are presented here to keep the report to a reasonable size. In addition, the distribution of measured and modeled wave heights in 0.5-m increments and periods in approximately 1.0-sec increments are presented.

20. A comparison is also made of the wind speed and direction input to the model and those measured at the six different buoys. These values are not independent, since measured wind information from buoys and ships is used by FNOC to calculate the global wind fields. This does, however, provide a check on the winds, even though the values are expected to agree. Example time series comparisons of wind speeds and directions are presented in Appendix A, along with wave heights and periods (pp. A9-A12).

Wave heights

21. Example plots comparing measured and modeled wave heights by month are presented in Appendix A. In general, the curves follow each other, but there is a pattern of underprediction related to high winds veering in direction. As an example, consider the wave heights measured at buoy 42002 and hindcast at WIS station 54 during January (p. A10). There are three times (approximately on the 3rd, 14th, and 25th) when the model underpredicts the buoy by 1.5 to 2.0 m. Each of these is associated with the passage of an atmospheric front in which the wind veers in direction and increases in speed in about a half day's time (p. A9). Part of this underprediction may be due to underestimation of the wind speeds. In each of these cases, maximum wind speeds at this location are about 5 knots lower than the approximate 25 knots measured by the buoy.

22. Since the wave height is proportional to the square of the wind speed, an underestimation of relatively small percentage, if present over a

large fetch, could significantly affect the wave height. For example, if the wind speed used over a large region is 20 knots, and the actual value is 25 knots, the value used is 25 percent low. The squares of 20 and 25 are 400 and 625, respectively, a difference of 56 percent; hence, the wave height could be 56 percent low if not fetch-limited.

23. At the same location (buoy 42002, WIS 54), during February 5-8, the model accurately predicted the increase in wave height due to an increase in wind speed over a relatively long time when the wind direction is steady (pp. A11-A12). At other times of the year, and at other locations, the model underpredictions seem to be associated with the passage of fronts and wind directions veering over about 12 hr. Modeled wind speeds are also underestimated at these times.

24. Table 3 summarizes the biases and RMS differences of wave height by month at each measurement location. The number of cases compared at each location and month is shown at the bottom of the table. The biases are generally less than 0.5 m and mostly negative, indicating that the model slightly underestimates measured conditions. Underestimating the peak wave heights (as discussed above) would contribute to this slight negative bias. The RMS differences are generally less than 0.5 m. Many are within the accuracy of the buoy, which for recent measurements is ± 0.2 m, or 5 percent of the wave height.

25. The distribution of wave heights for different height categories at the location of buoys 42003, 42001, and 42002 in the central Gulf of Mexico is shown in Appendix A (pp. A13-A15). Distributions are from WIS results and available buoy data during 1988. The WIS results overestimate the number of occurrences of waves less than 0.5 m by about 12 percent. The hindcast underestimates, by about 5 percent, the number of occurrences for waves greater than 1.5 m with respect to the buoy data. This is in part due to underestimating winds and wave heights during high wave events.

<u>Wave peak periods</u>

26. Plots comparing measured and modeled peak period for the times mentioned above are located in Appendix A (pp. A10 and A12). In general, the curves follow each other. There is a tendency for the periods to be underestimated at those times that the wave heights are underestimated coincident with the passage of a front.

27. Table 4 summarizes the biases and RMS differences of peak period, by month, at each location site. Biases are generally below 1 sec and consistently negative, indicating that the model slightly underestimates peak period. The RMS differences are generally about 2 sec or less. Buoy accuracy is ± 1 sec.

28. Distributions for wave periods are shown on pages A13-A15. The WIS overestimates the number of occurrences of peak periods below about 5 sec and underestimates the number of periods greater than 5 sec. The lowest period the buoy reports is 3 sec, while the model calculates periods below 1 sec. This could contribute to the larger number of low periods from the model.

Conclusions

WIS winds

29. There is an indication, in both sets of time series plots (pp. A3-A5 and A9-A12), that calculated WIS winds may be underestimated for wind speeds above about 20-25 knots. This may be a result of past and present-day wind models not exactly representing the events producing these high wind speeds. Usually, in the Gulf of Mexico, these events are associated with the passage of fronts in the fall and winter producing northerly winds and, hence, waves propagating offshore. Thus, it is not of critical importance for design purposes at the coast.

30. The distribution of WIS wind speeds and directions over speed and directional categories generally agrees with these buoy-measured values. Values of bias and RMS difference are 1.5 knots and 4.5 knots, respectively, for WIS and measured data available at one site for the same time period. It is concluded that the WIS wind-field data calculated over the Gulf of Mexico for 20 years satisfactorily represent the climatology of the region. There is some evidence that high wind speeds due to frontal passages may be underestimated.

Wave results

31. The monthly time series plots of wave height and peak period show very good agreement most of the time. This is indicated quantitatively by low values of bias and RMS difference. There is an indication that during times of high wind speeds, wave heights and periods may be underestimated. Part of

this may be due to the underestimation of wind speeds noted above. It is concluded that the WIS wave information satisfactorily represents the wave climatology in the Gulf of Mexico. There is evidence, particularly from the mid-gulf comparisons, that high wave events may be underestimated. However, these events are usually related to offshore winds and in those cases will not affect use of the information for coastal engineering purposes.

Recommendations

32. Based on the 1988 hindcast, users of the WIS Gulf of Mexico data set for the period 1956-75 should interpret the data to have the following range of accuracies:

a. Wind speed: low in the mean by 2.5 knots; RMSD 3.5 knots.

b. Significant wave height: low in the mean by 0.1 m; RMSD 0.25 m.

c. Peak period: low in the mean by 1 sec; RMSD 2 sec.

Additionally, wind and wave conditions for "Norther" events in non-coastal waters may be low.

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Table 1

Locations of Measurements and Model Results

Buoy ID	Latitude deg N	Longitude deg W	Depth meters	Model Sta.	Latitude deg N	Longitude deg W	Depth meters
42001	25.9	89.7	3,200	53	26.0	89.5	3,200
42002	26.0	93.5	2,400	54	26.0	93.5	2,400
42003	26.0	85.9	3,200	52	26.0	86.0	3,200
42007	30.1	88.9	10	26	30.0	88.5	25
42015	30.2	88.2	18	26	30.0	88.5	25
42016	30.2	88.1	18	27	30.0	88.0	25
U of FL	28.0	82.8	5	39	28.0	83.0	11

Table 2

Summary Statistics for FNOC Winds in 1988

Bias* (knots) of FNOC Wind Speeds to Measured at Buoys by Month

Buoy	J	F	M	A	M	J	J	A	S	O	N	D
42001	0.3		-1.0	-1.4	-2.7					-1.5	-2.3	-0.5
42002	-3.3	-2.2	-3.3	-2.2	-3.1		-1.4	-1.5	-2.1	-2.6	-3.9	-3.8
42003							-1.8	-1.9	-1.7	-2.3	-3.6	-3.4
42007			-3.1	-3.6	-3.0		-3.6	-3.8	-2.7	-3.5	-3.2	-2.8
42015	-2.2	-1.5	-2.2	-2.6	-1.9		-2.7	-3.3				-0.9
42016					-2.0		-2.9	-3.2	-1.7	-2.8	-2.3	-2.0

RMS Difference (knots) of FNOC Wind Speeds from Buoy

Buoy	J	F	M	A	M	J	J	A	S	O	N	D
42001	4.3		3.7	2.9	3.9					3.2	4.1	4.0
42002	3.7	4.0	3.6	4.0	2.8		3.2	3.0	3.8	2.8	4.0	3.4
42003							2.4	2.8	3.4	2.7	4.9	3.7
42007			3.4	3.3	3.1		2.9	4.8	4.8	3.0	3.8	3.1
42015	2.8	3.7	3.3	3.1	2.6		2.1	3.8				2.9
42016					2.6		2.0	3.0	4.1	2.4	3.2	3.1

Number of Cases Compared

Buoy	J	F	M	A	M	J	J	A	S	O	N	D
42001	119		160	240	246					148	240	246
42002	247	230	248	237	214		245	246	238	245	239	245
42003							246	247	239	248	237	247
42007			248	235	246		241	187	238	242	239	247
42015	246	230	245	237	242		244	242				135
42016					246		247	246	239	244	239	112

*Bias = Calculated monthly average - measured monthly average.

Table 3

Summary Statistics for Model Wave Heights for 1988

Bias* (meters) of Wave Height From Measurements

Buoy	J	F	M	A	M	J	J	A	S	O	N	D
42001	-0.3		-0.2	-0.1	-0.2					-0.2	-0.4	-0.2
42002	-0.5	-0.2	-0.2	-0.2	-0.3		-0.1	-0.1	-0.1	-0.4	-0.3	-0.4
42003							-0.2	-0.3	-0.2	-0.3	-0.6	-0.4
42007	0.0	0.1			0.1		0.0	-0.1	0.2	0.0	0.1	0.0
42015	0.0	0.1	0.0	0.0	-0.1		-0.1	-0.2				-0.2
42016					0.0		0.0	0.0	0.3	0.0	0.1	0.1
CDN	0.2	0.4	0.2	0.2	0.1		0.0	0.0	0.4	0.1	0.3	0.1

Root Mean Square Difference (m) of Wave Height

Buoy	J	F	M	A	M	J	J	A	S	O	N	D
42001	0.5		0.4	0.4	0.4					0.3	0.5	0.3
42002	0.5	0.5	0.5	0.4	0.2		0.2	0.2	0.8	0.4	0.4	0.3
42003							0.2	0.2	0.5	0.3	0.8	0.4
42007	0.3	0.3			0.2		0.2	0.3	0.4	0.2	0.3	0.2
42015	0.4	0.3	0.3	0.3	0.2		0.2	0.3				0.4
42016					0.2		0.1	0.2	0.4	0.3	0.3	0.3
CDN	0.3	0.3	0.4	0.4	1.0		0.1	0.2	0.4	0.3	0.8	0.3

Number of Cases

Buoy	J	F	M	A	M	J	J	A	S	O	N	D
42001	106		159	240	246					246	239	245
42002	247	231	248	239	144		246	246	237	246	238	247
42003							245	242	238	248	236	244
42007	237	215			245		246	144	237	238	224	228
42015	247	230	247	233	246		245	234				132
42016					246		247	245	238	234	228	105
CDN	102	31	72	86	15		40	108	82	60	10	111

*Bias = Calculated monthly average minus measured monthly average.

Table 4

Summary Statistics for Model Periods for 1988

Bias* (seconds) of Wave Peak Period from Measurements

Buoy	J	F	M	A	M	J	J	A	S	O	N	D
42001	-0.7		-0.5	-0.7	-0.9					-1.1	-0.7	-1.0
42002	-0.9	-0.6	-0.3	-0.7	-0.9		-1.4	-1.5	-0.3	-1.3	-0.5	-0.9
42003							-2.3	-2.8	-0.3	-1.6	-1.4	-1.3
42007	-0.2	0.3	-0.6		-0.1		-0.8	-0.9	0.2	-0.6	0.1	-0.5
42015	-0.4	-0.1	-0.9	-0.6	-1.0		-1.1	-1.5				-1.4
42016					-1.1		-1.0	-1.4	-0.3	-0.4	-0.3	-0.4
CDN	0.0	0.2	-0.6	-0.7	-1.1		0.2	-1.1	-0.3	0.5	0.7	-0.6

RMS Difference (seconds) of Peak Period

Buoy	J	F	M	A	M	J	J	A	S	O	N	D
42001	1.7		0.9	1.4	1.9					1.3	1.4	1.1
42002	1.5	1.3	1.4	0.9	1.1		2.1	1.5	1.5	1.4	1.3	1.6
42003							2.3	1.9	2.2	1.5	1.2	1.1
42007	2.3	2.2	1.8		2.4		2.1	1.6	2.0	2.0	1.8	1.9
42015	2.3	2.1	2.2	2.0	2.5		1.7	1.6				1.7
42016					2.6		1.7	1.8	1.9	2.0	2.1	2.3
CDN	2.1	1.6	2.0	2.0	3.5		1.9	1.7	4.1	2.5	2.2	2.0

*Bias - Calculated monthly average minus measured monthly average.

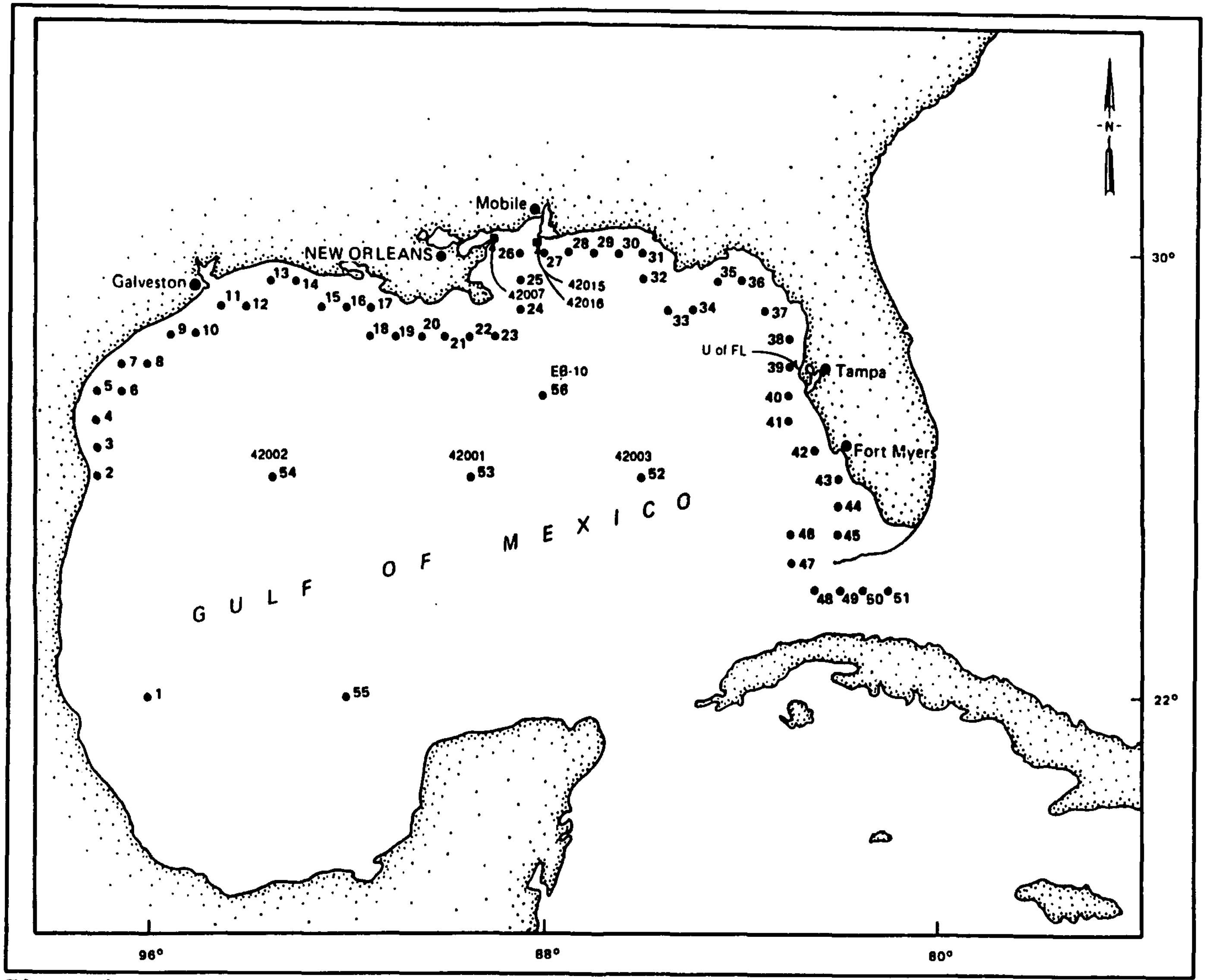
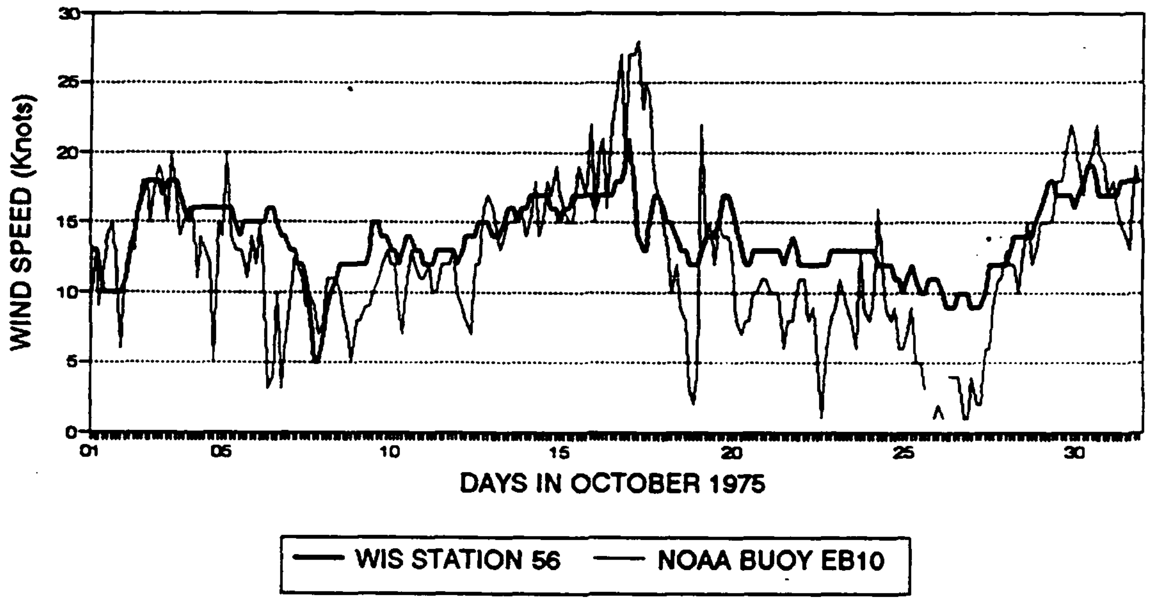


Figure 1. Location of WIS stations (numbered dots) and measurement sites.

APPENDIX A: TIME HISTORIES, DISTRIBUTIONS, AND COMPARISONS OF WIND SPEEDS AND DIRECTIONS, WAVE HEIGHTS AND PERIODS

GULF OF MEXICO VERIFICATION
WIS STATION 56 VS NOAA BUOY EB10



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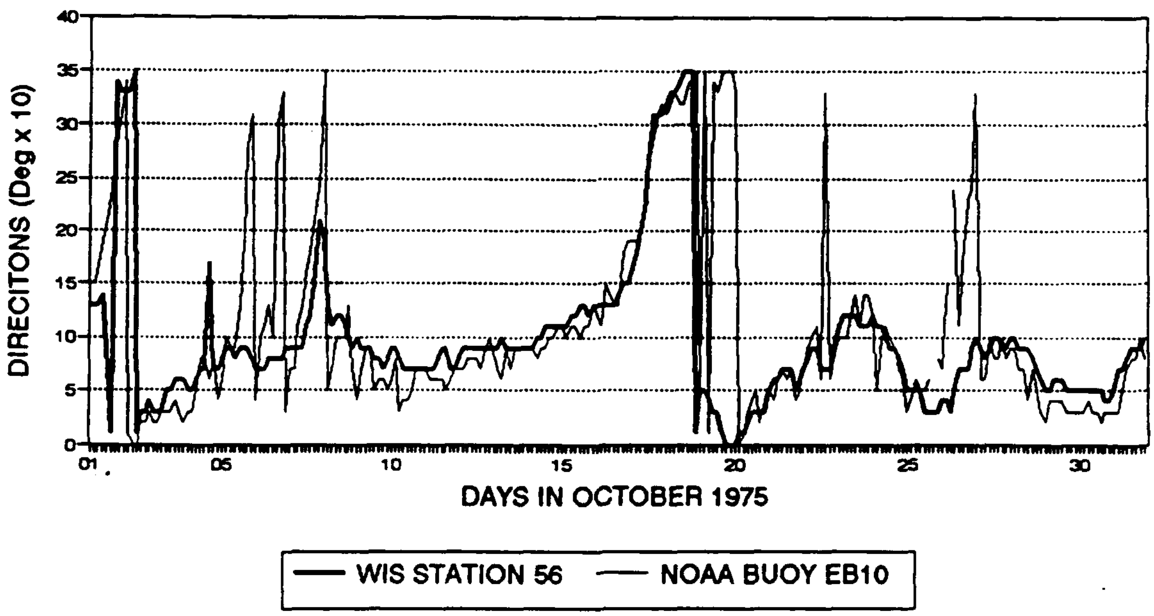
WIS STATION 56 VS NOAA BUOY EB10



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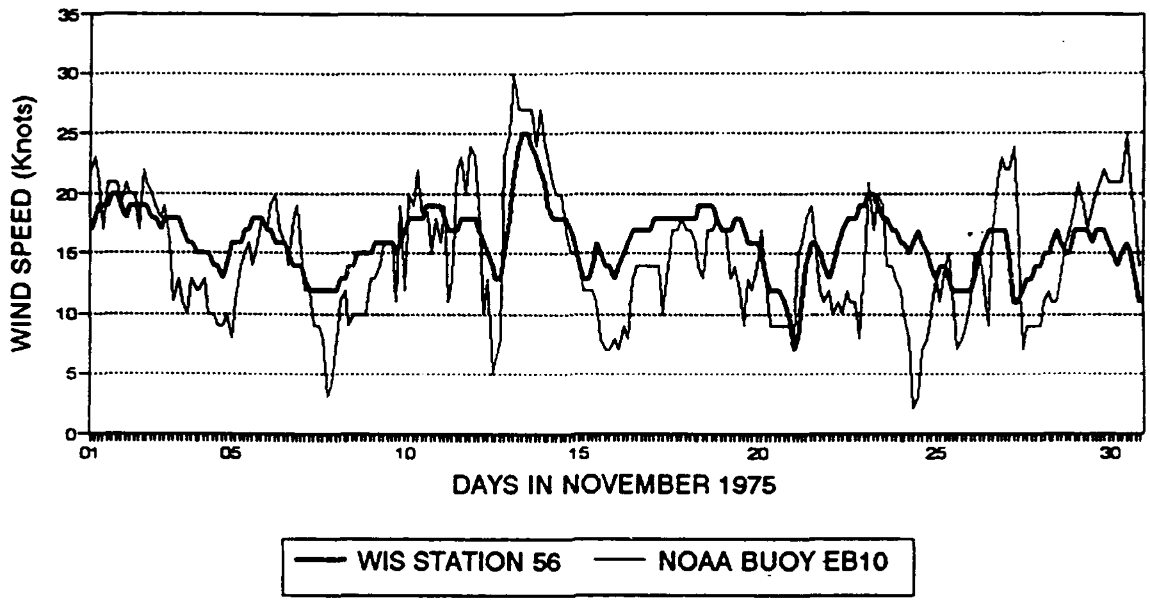

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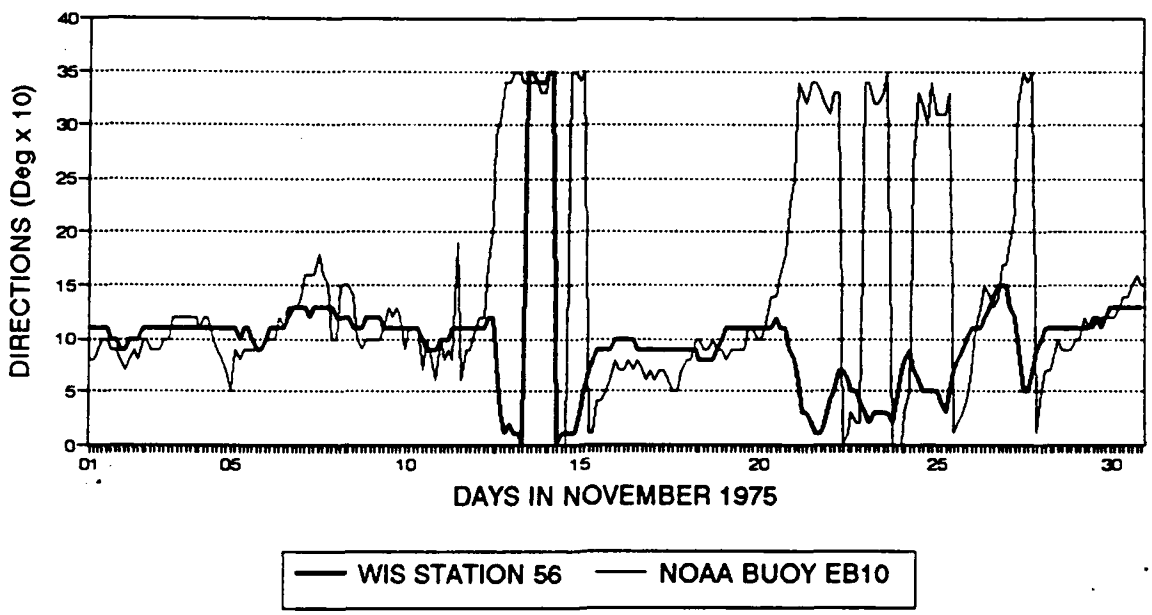

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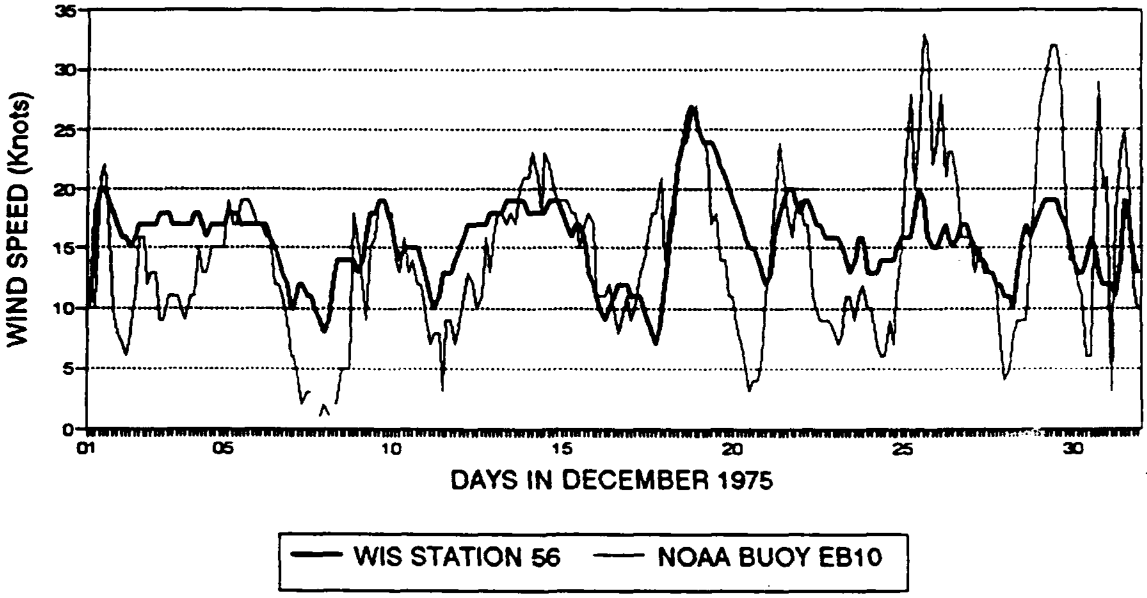

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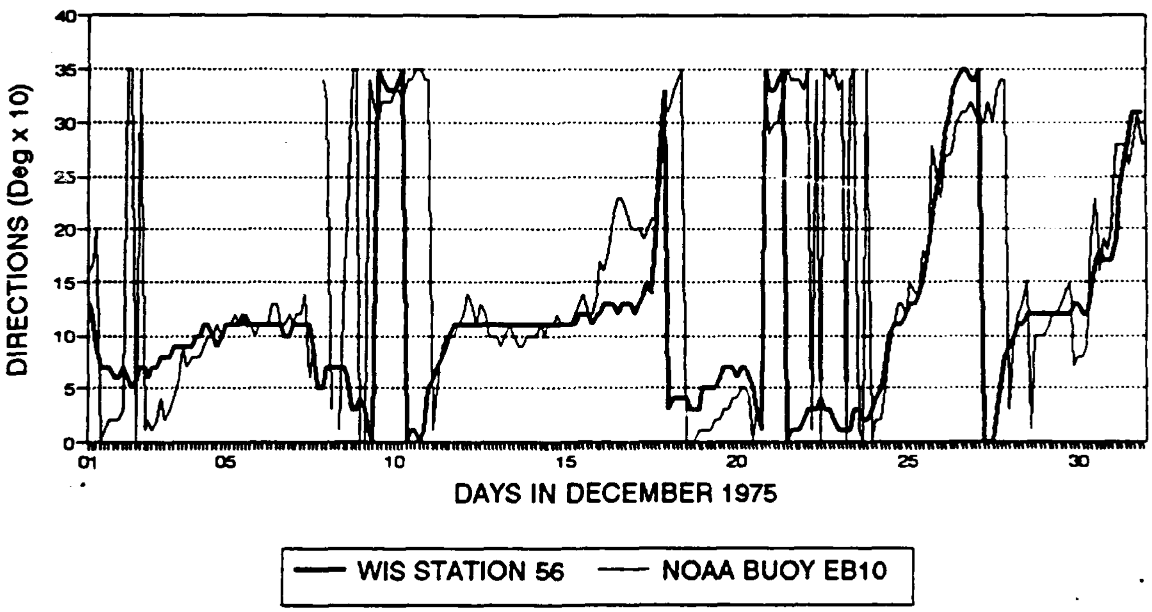
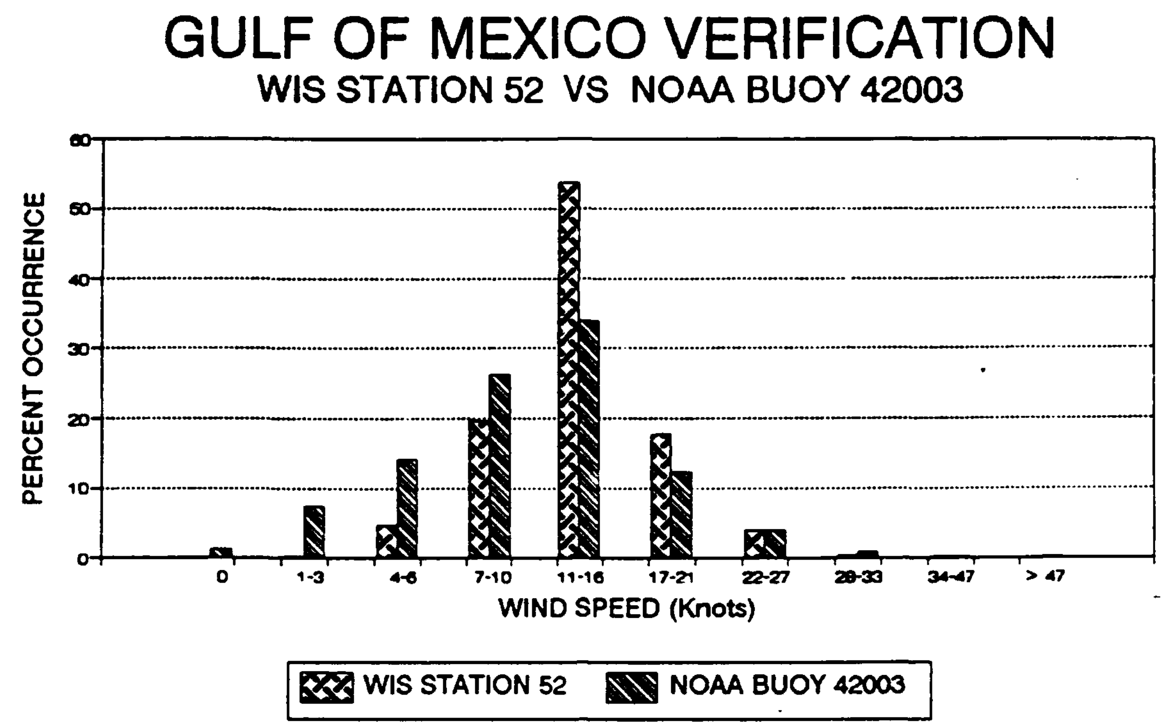
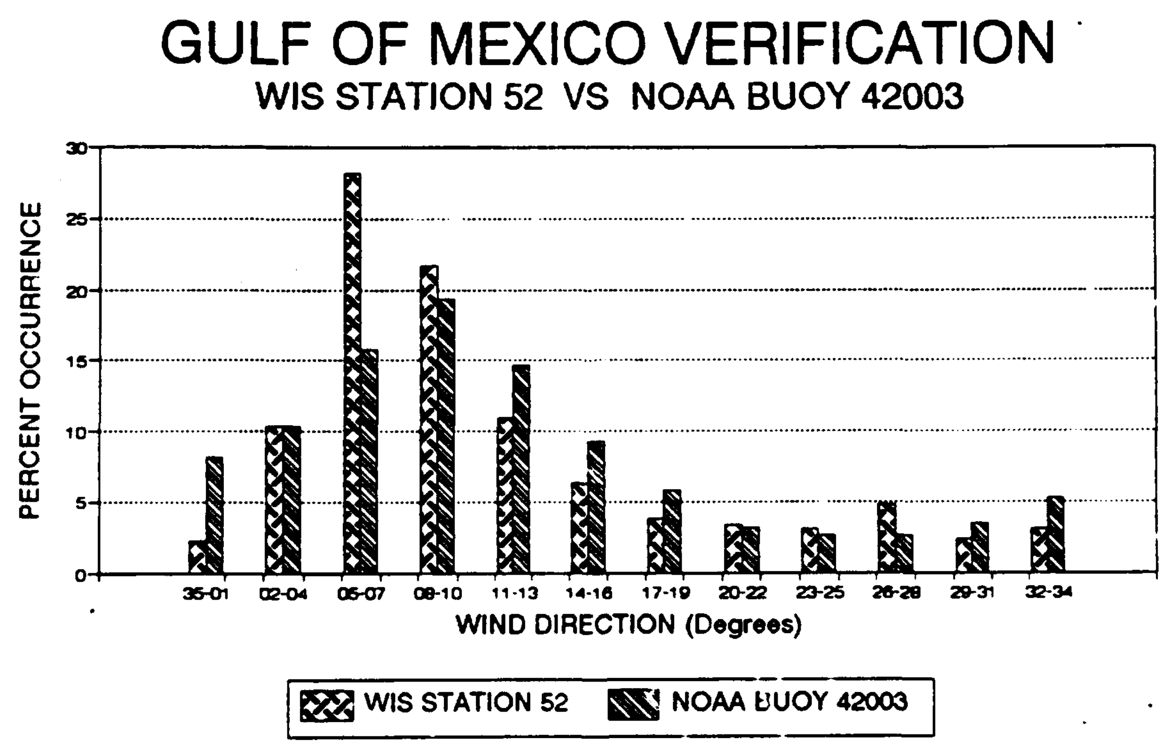
WIS STATION 56 VS NOAA BUOY EB10

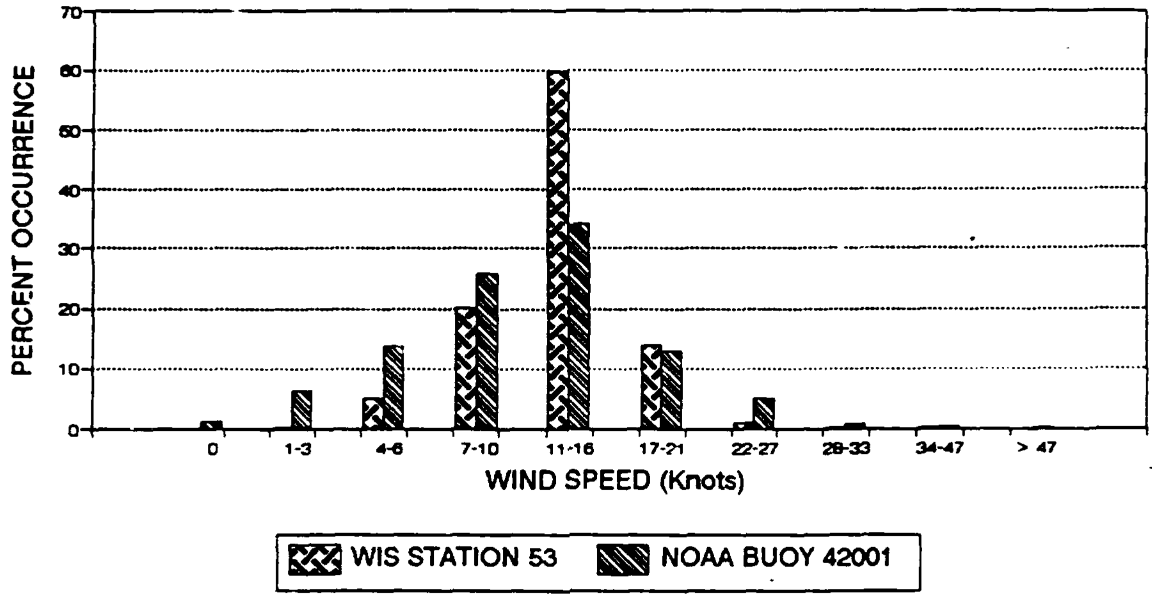



GULF OF MEXICO VERIFICATION
WIS STATION 52 VS NOAA BUOY 42003
PERCENT OCCURRENCE
WIND SPEED (Knots)
0
1-3
4-6
7-10
11-16
17-21
22-27
28-33
34-47
> 47
WIS STATION 52
NOAA BUOY 42003


GULF OF MEXICO VERIFICATION
WIS STATION 52 VS NOAA BUOY 42003
PERCENT OCCURRENCE
WIND DIRECTION (Degrees)
35-01
02-04
05-07
08-10
11-13
14-16
17-19
20-22
23-25
26-28
29-31
32-34
WIS STATION 52
NOAA BUOY 42003

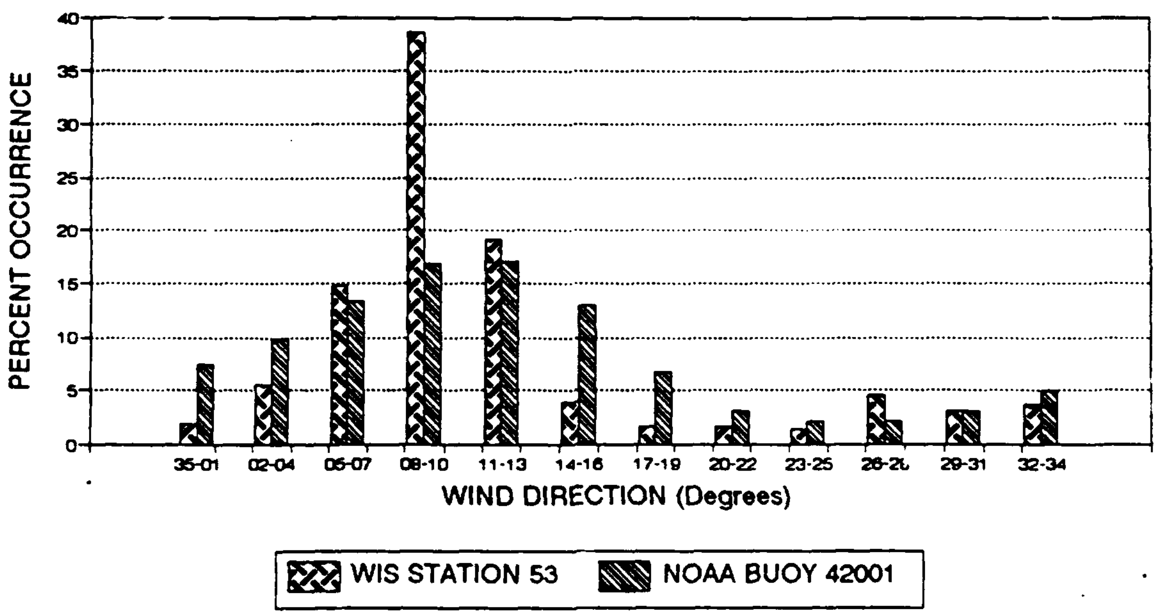
GULF OF MEXICO VERIFICATION

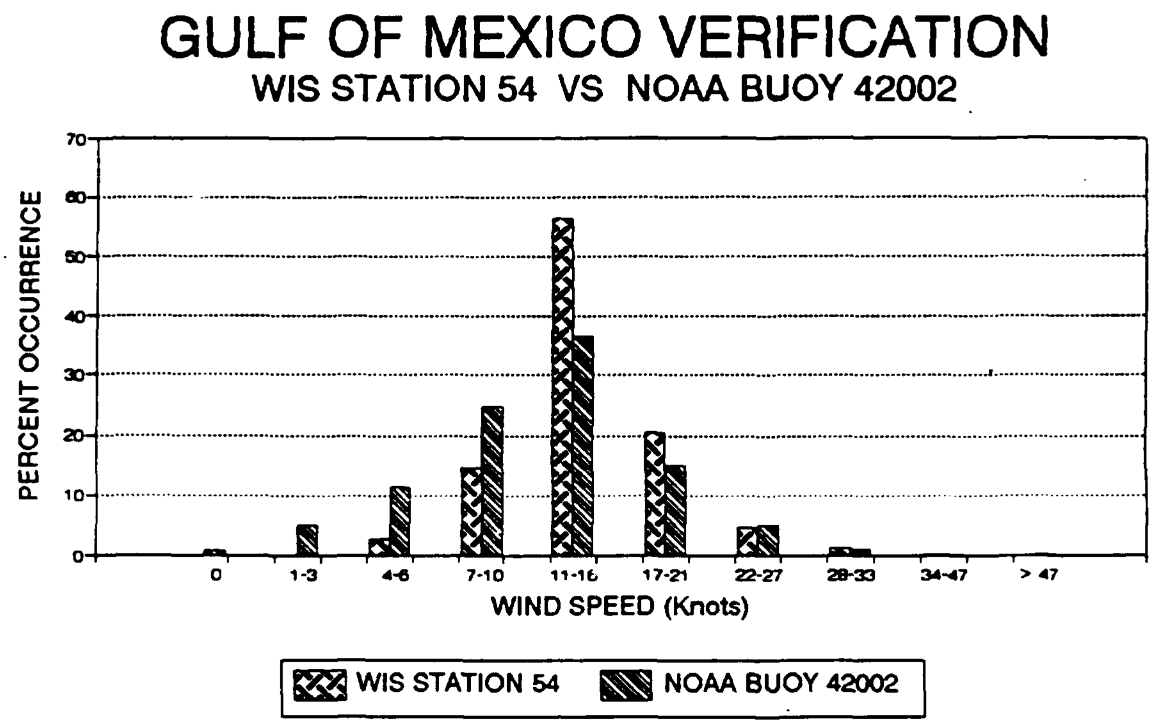
WIS STATION 53 VS NOAA BUOY 42001

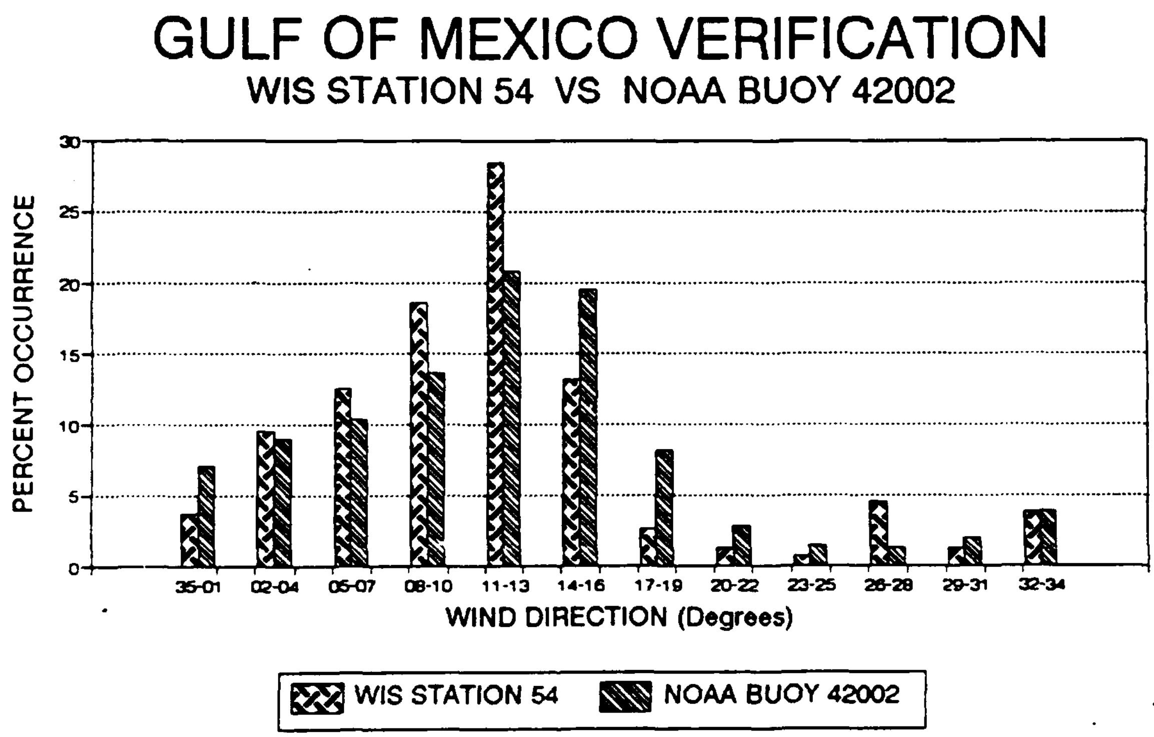


GULF OF MEXICO VERIFICATION

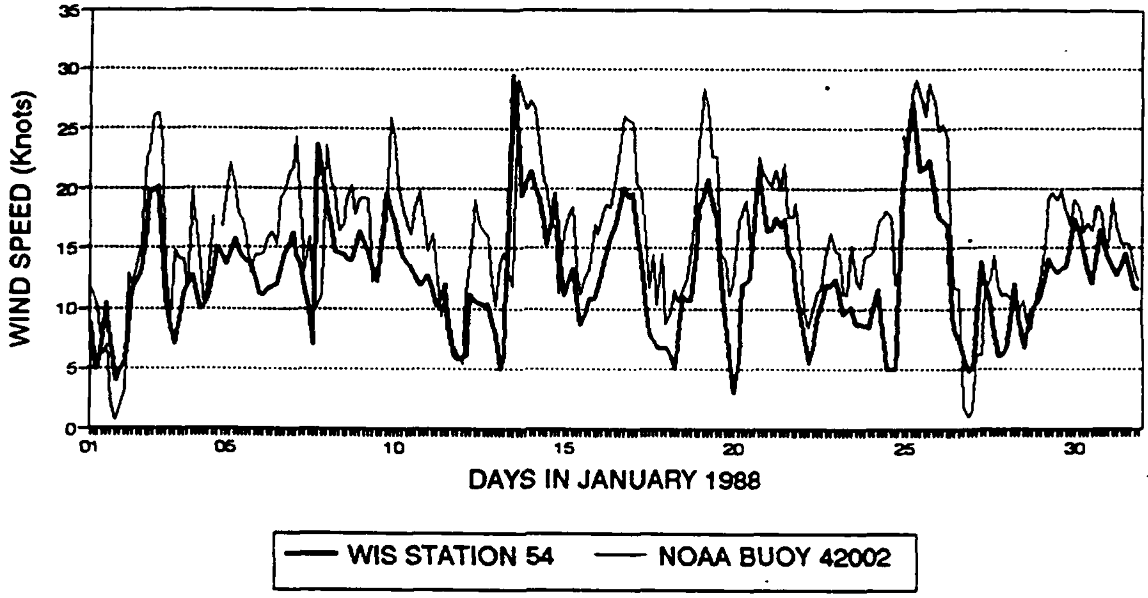
WIS STATION 53 VS NOAA BUOY 42001




GULF OF MEXICO VERIFICATION
WIS STATION 54 VS NOAA BUOY 42002
PERCENT OCCURRENCE
0
10
20
30
40
50
60
70
0
1-3
4-6
7-10
11-16
17-21
22-27
28-33
34-47
> 47
WIND SPEED (Knots)
WIS STATION 54
NOAA BUOY 42002


GULF OF MEXICO VERIFICATION
WIS STATION 54 VS NOAA BUOY 42002
PERCENT OCCURRENCE
0
5
10
15
20
25
30
35-01
02-04
05-07
08-10
11-13
14-16
17-19
20-22
23-25
26-28
29-31
32-34
WIND DIRECTION (Degrees)
WIS STATION 54
NOAA BUOY 42002

GULF OF MEXICO VERIFICATION
WIS STATION 54 VS NOAA BUOY 42002



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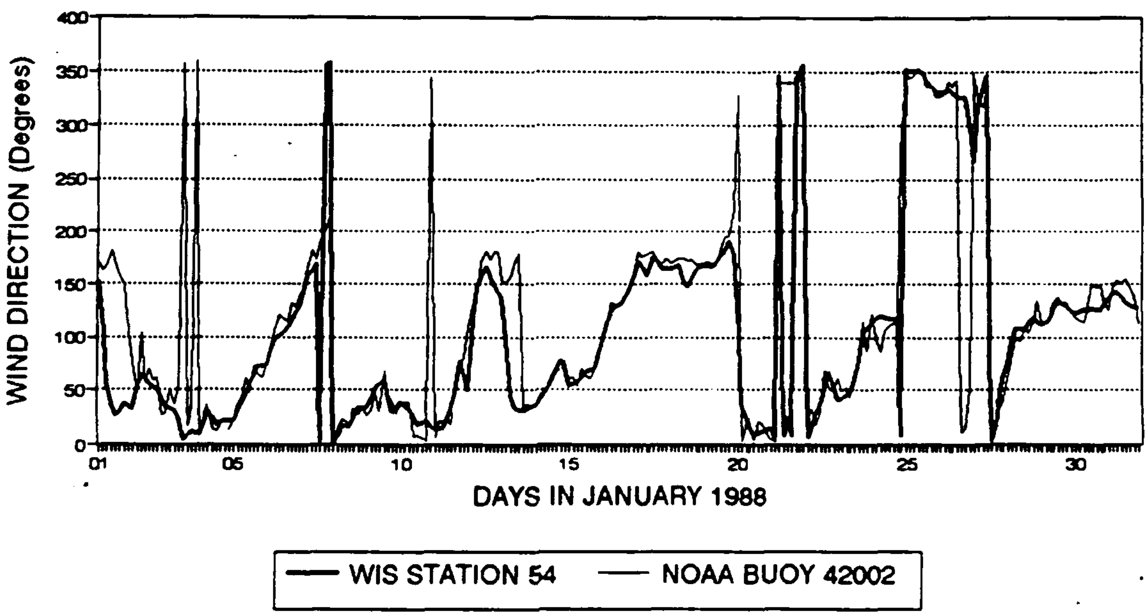

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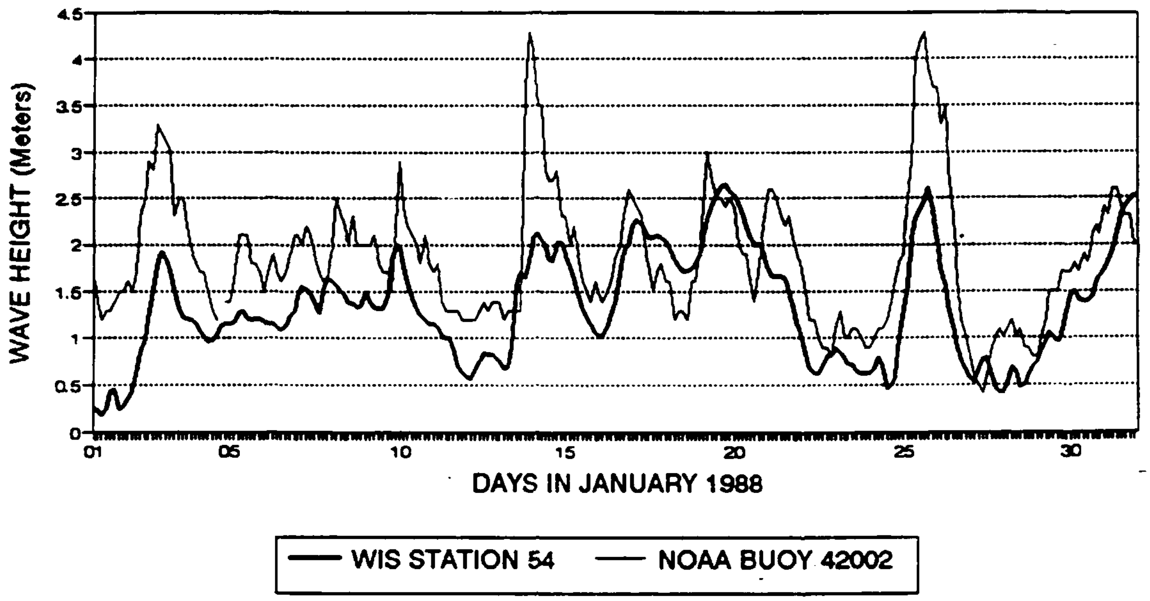

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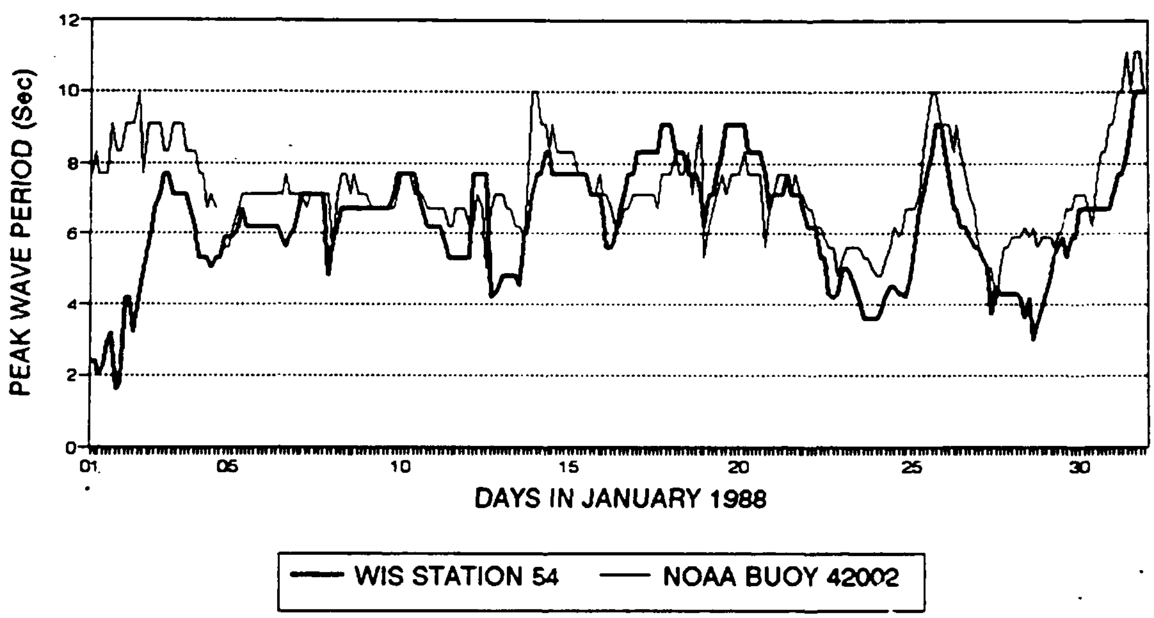

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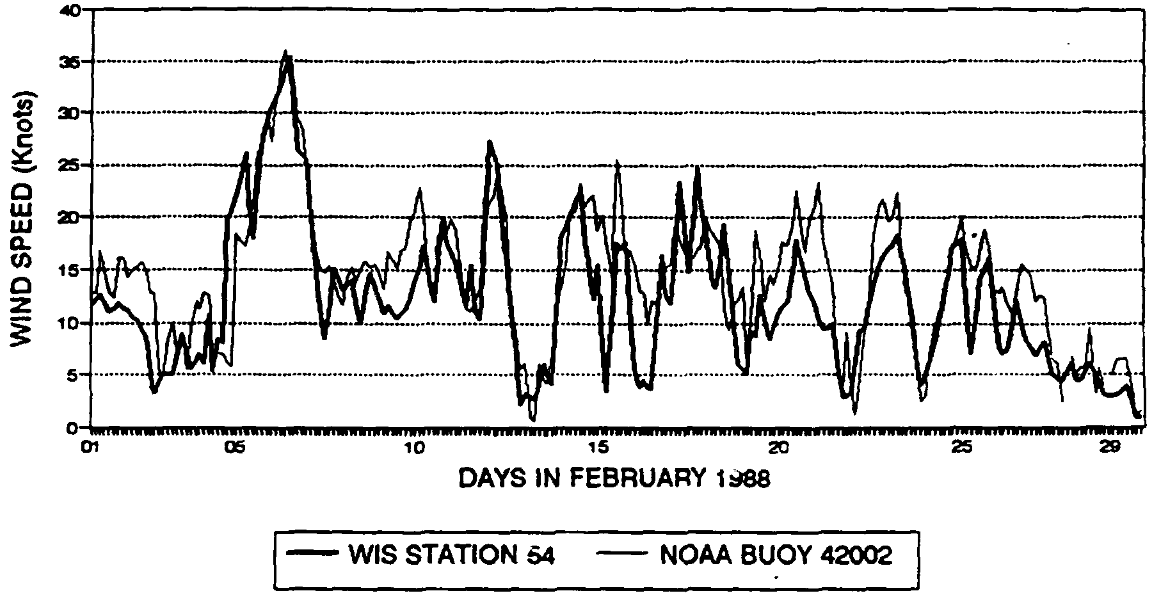

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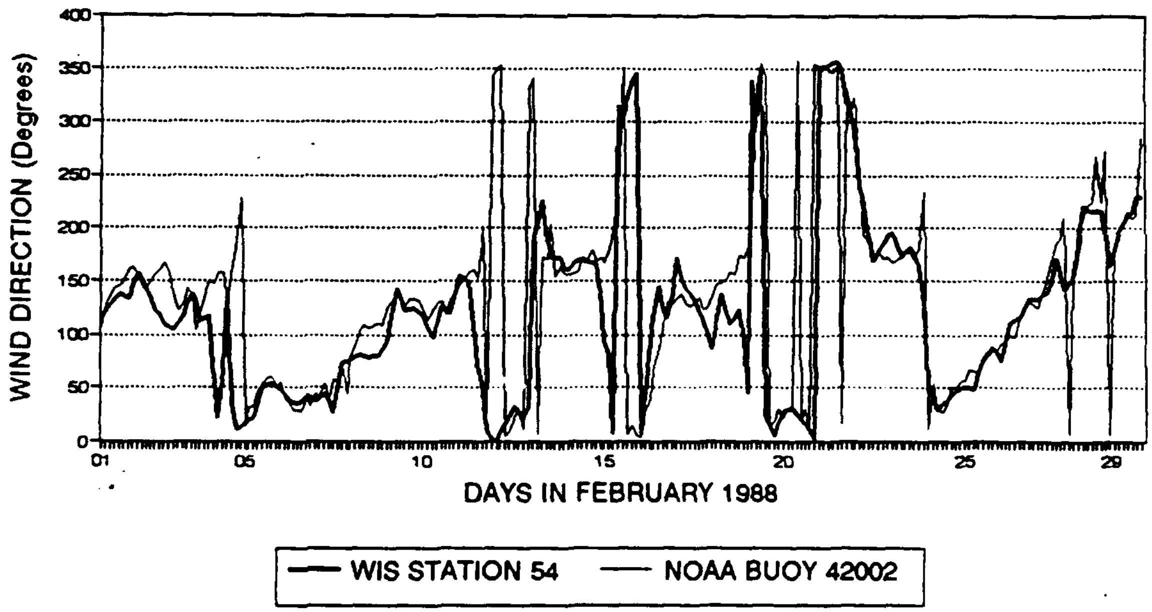

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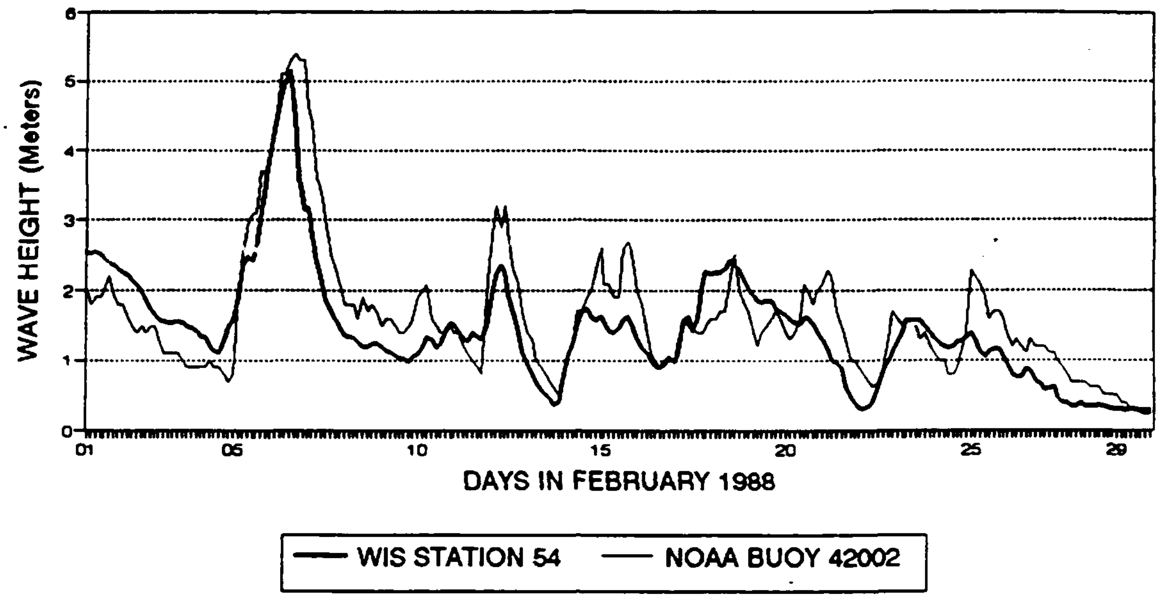

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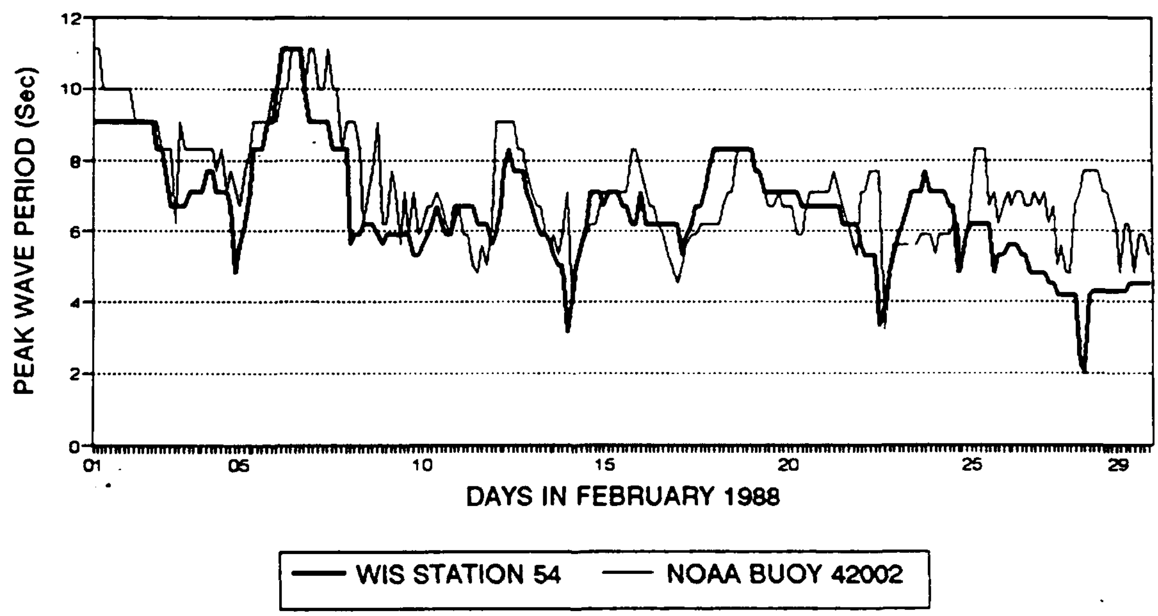

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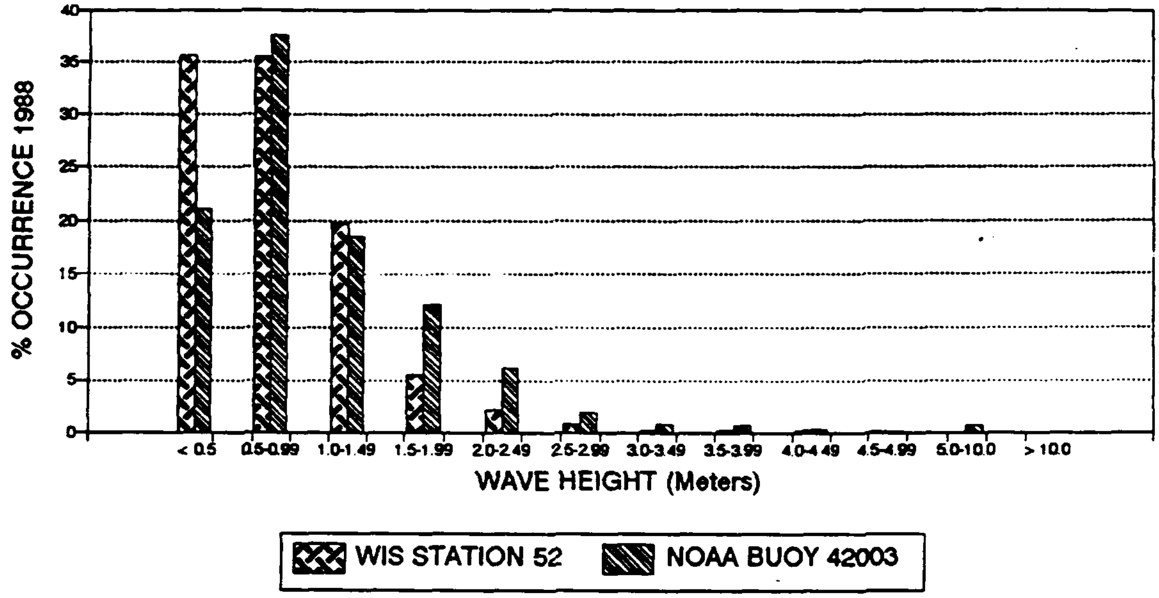
WIS STATION 52 VS NOAA BUOY 42003



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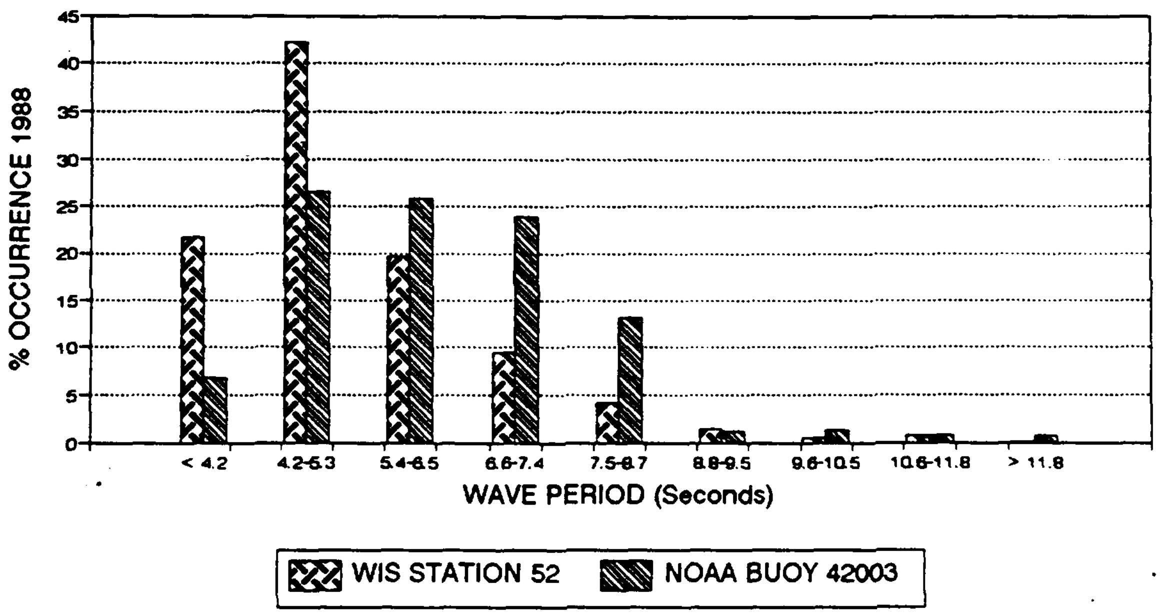

GULF OF MEXICO VERIFICATION
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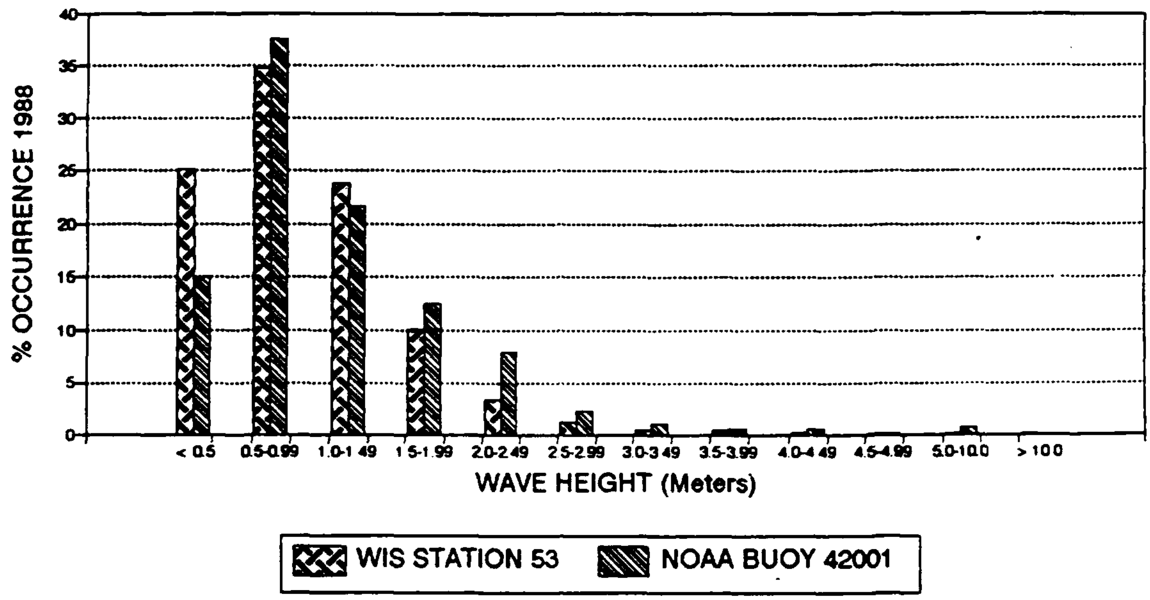

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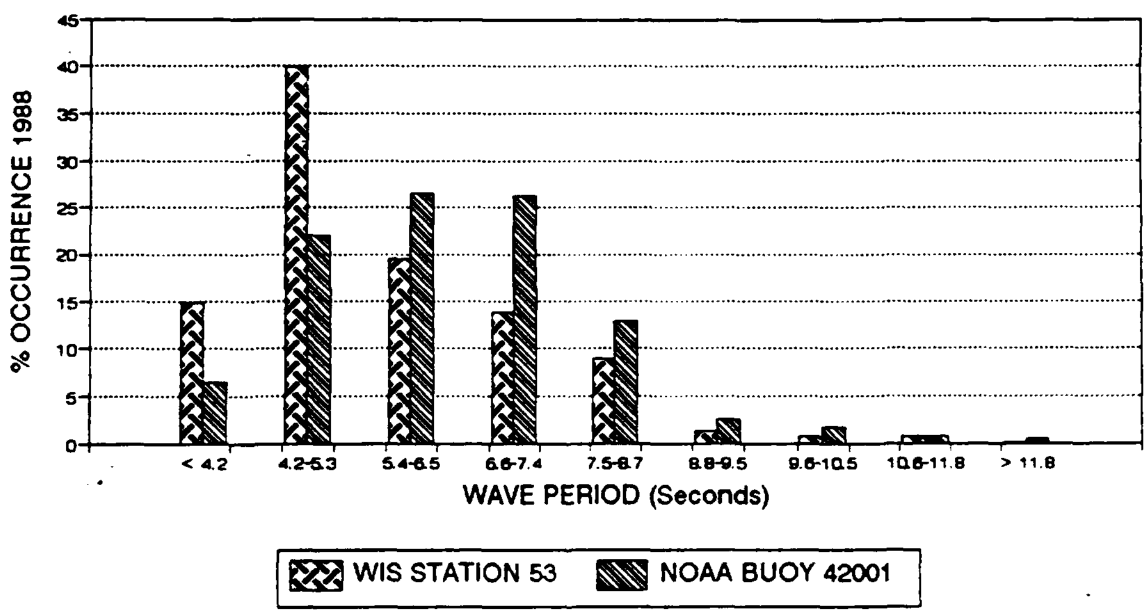

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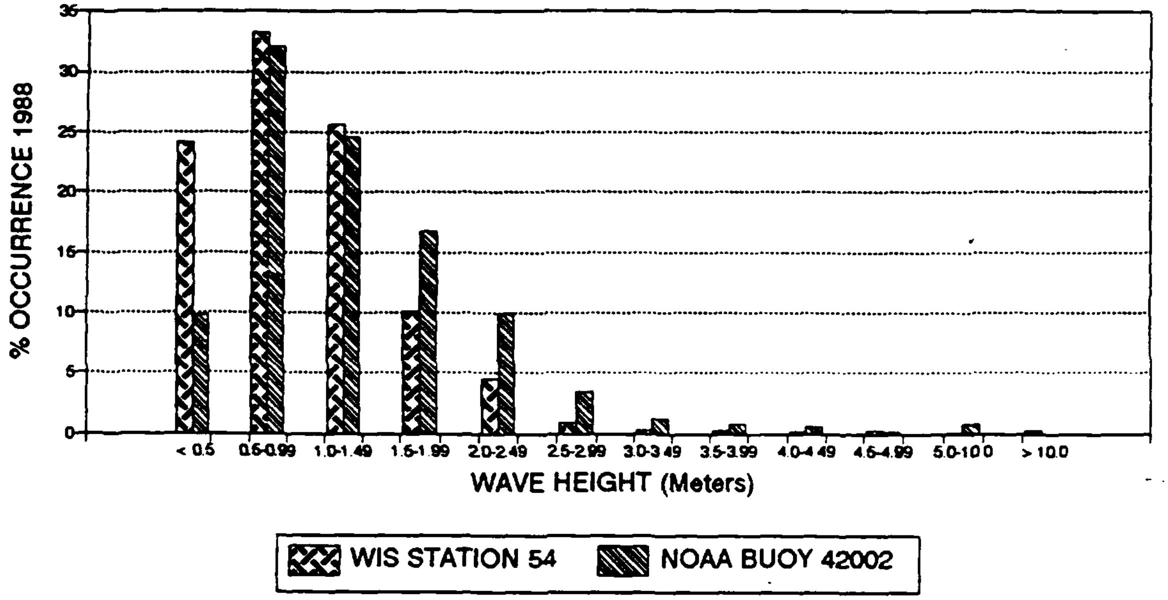

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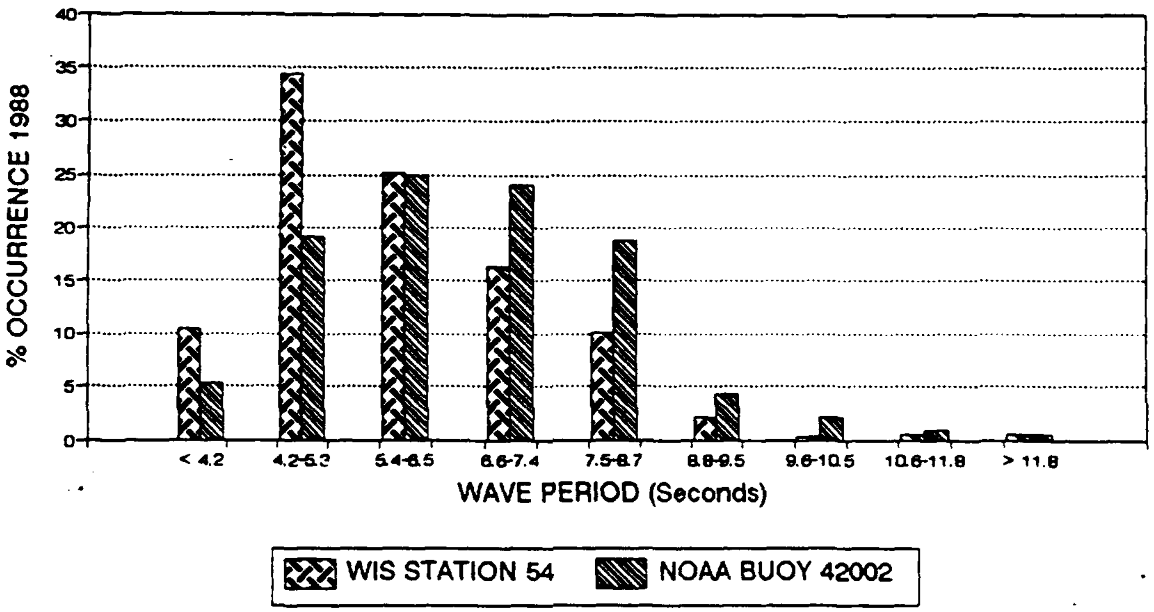

Waterways Experiment Station Cataloging-in-Publication Data

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